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Disinfection Process with Solar Drying System

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ABSTRACT

COVID-19 has become a health threat around the world. Mask deficiency can be expected during a pandemic infection. The stability of viruses at different temperatures and relative humidity was assessed according to the type of contaminated surface material. With increasing temperature, the permanence of viruses decreases, and in proportion to the increase in temperature should not be damage to the quality of objects. Solar disinfection is one of the new methods of using renewable resources. By designing an integrated solar drying system with the phase change material, the internal temperature of the system reaches 54° C in April and the masks are disinfected with 3036 Wh/m^2 internal cumulative solar radiation. By using the appropriate equipment in the system, the temperature difference inside and outside the system was reached 30°C. A correlation coefficient of 95% in the MATLAB confirmed that the curve fit was good. The main purpose of this research is to identify appropriate solutions for disinfection and consultation with scientific literature. The results showed that the most appropriate hygienic and economical disinfection method was the use of solar energy.

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1. Introduction

Waste management has become a problematic issue due to the high humidity and possible dangers during transportation. These wastes must be completely dried and disinfected before use for any type of operation. The process of solar drying is a common method of sanitary disinfection in accordance with international standards [1].

Viruses maintain their stability on surfaces at different temperatures and humidity. Dry viruses survive on smooth surfaces at 22-25 ° C and 40-50% relative humidity for more than 5 days, and the survival time of viruses decreases with increasing temperature [2]. In today's world, various methods and technologies have been proposed for disinfection. Different types of epidemics have led to a global shortage of masks and their raw materials, forcing people to produce masks from home appliances [3].

The cleaning and disinfection process are evaluated by microbiological methods [4]. Due to the prevalence of the Covid-19 virus in recent months, face masks that have been considered a hazardous waste, as well as proper disposal or reuse, have become a problem for many organizations. Many face masks can be used for only a few hours and then need to be replaced quickly, so it has a high consumption, also the public should discard them separately into the trash. It is significant that the collection of such waste is challenging and considered risky. Because many of these hazardous wastes carry contaminants, and viruses can also survive for some days in humid conditions, so they should not be accidentally disposed of with other wastes. Medical waste must be collected under certain conditions and transported by qualified individuals. Experiments on the reuse of facial masks by spraying 75% alcohol on the outer layer and washing the surgical mask with soapy water at 60 ˚C under an electron microscope showed that the outer layer of the mask was damaged and fibrous. The middle layer is also crushed, and this cleaning functions are not preferred [5].

Disposable masks can be reused for a limited time. Methods of using H_2O_2 and warm air to disinfect face masks have been suggested [6]. Another method is washing with soapy water, which changes the shape of the mask and affects the electrostatic properties of the fibers [7]. The other methods for disinfecting are Oven drying, High temperature, Steamer wet heat, High-pressure disinfection, and Ultraviolet disinfection. In the study

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between Fudan University Shanghai Medical College and Ministry of Education/Medical Molecular Virology Laboratory and School of Public Health, it has been found that medical masks can be disinfected for 30 minutes by placing them in a Zip bag and blasting them with a hairdryer [8]. The drying process is one of the proposed methods to facilitate disinfection. Drying method is done in three types: convective, conductive, and solar drying [9]. Solar dryers are valuable because they are easy to install and have no fuel costs [10]. Many respiratory viruses, especially COVID-19, can live up to 72 hours at different surfaces [11]. According to the researchers, the highest transmission of the Corona virus occurred in areas with temperatures between 3 to 17 degrees celsius, also, at an average temperature above 18 °C, their number decreases by about 6% [12]. According to a study by the Chinese Academy of Military Medical Sciences, the resemblance between the Coronavirus and SARS virus indicates that SARS survives at 4˚C and becomes inactive at 37˚C during 3 days. It also survives for only 15 minutes at 70˚ C. Applying the mask at 75˚ C for 30 minutes disables viruses, even at 85˚C or 100˚C, but at 125˚C, it destroys the performance of mask polypropylene. Solar dryers play an important role in reducing pathogens [13]. As a result of heat and mass transfer the temperature inside the system changes using phase change material (PCM) [14]. Many studies have been conducted on the use of PCM in solar dryers for thermal storage [15, 16]. One of the most common materials is paraffin-wax phase change material, which greatly increases system performance [17, 18].

In this article, the main disinfection strategies and their effectiveness have been studied using the scientific literature. During this research, a comprehensive review of previous publications has been analyzed.

To identify the disinfection method, the advantages and disadvantages of this method were investigated.

In special circumstances caused by epidemics, and severe shortages of masks, low-cost strategies are considered. The content of the article may also be quoted for commercial use. Reuse of face masks is limited in terms of number of uses. Among the various disinfection methods, the solar method is a cost-effective method for reuse with special restrictions without deformation in a short time. The solar drying system is installed on the campus of Uludag University in Bursa/Turkey for various purposes.

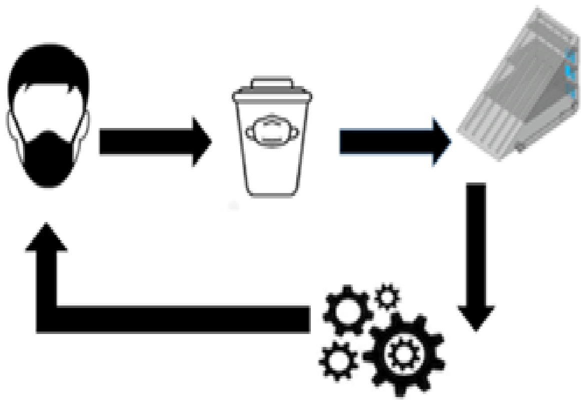

Figure 1. The mask reuse cycle.

2. Material and Methods

The facial mask is designed to protect people against gases or other types of fluid. Surgical masks consist of three layers. There is a material melted between non-woven fabrics and acts as a filter to prevent the entry and exit of microbes. The standard size of the surgical mask is 9.5*17 cm [19]. In this small-scale system, approximately 500 masks are easily disinfected in each loading series.

In this method, the main part of disinfection is done by sunlight. In Figure 1 shows the mask reuse cycle. After collection, the masks enter the drying system and after disinfection, they enter the classification process and are ready for reuse.

2.1. Experimental Study

The greenhouse drying system is a triangular with an aluminum frame and polycarbonate coating. This system is a mixed-mode type, which receives both direct and indirect solar radiation. Under the polycarbonate-cover, five glass heat pipes evacuated tubes with 1.80 m height from borosilicate were supplied in which the copper pipes are embedded. Each tube is also filled with 1kg of paraffin-wax phase change material. Solar radiation is collected by dark tubes and then the heat is transferred to copper pipes and paraffin-wax. Paraffin-wax stores heat when there is no sunlight. On the outside of the system, a white tube filled with silica gel was installed. One side of the white tube is connected to the pump and the other side is connected to the inside and bottom of the system. One kilogram of silica gel is inserted into the white tube, then the moist air is removed in by the pump, and the dried air is exited from the silica gel and re-enters the system. This system is completely closed and has no connection with the outside air. The sensors used in this study were HOBO data logger (RX2100, onset) and Comet (S3120), also, a Vaillant VCK pump was supplied at the bottom of the system. The back and underside of the system are covered with polyurethane insulation to prevent heat loss. Inside the system, horizontal bars are embedded throughout the system space, and masks are hung in a row. This study was performed experimentally on a facial mask that can also be used to disinfect various objects. Studies have shown that the resistance of different viruses at different temperatures on the surface of some objects is shown in Table 1. The highest survival of the virus is on plastic surfaces and the lowest survival is on aluminum. It is considered that with increasing temperature, the survival of viruses also decreases.

In this system, by increasing the internal temperature of the system, the conditions for killing viruses are provided.

In the Figure 1 the different components of the dryer system are clearly visible, and by installing different

Table 1.The duration of resistance of viruses on different objects.

Materials	Type of virus	Temperature ˚C	Persistence	Reference
Steel	MERS-CoV	30˚C	8-24 h	20
Metal	SARS-CoV	Room Temperature	5day	21
Aluminium	HCoV	21˚C	2-8h	22
Glass	HCoV	21˚C	5day	23
Wood	SARS-CoV	Room Temperature	4day	21
Plastic	MERS-CoV	20˚C	48h	20
Surgical glove (latex)	HCoV	21˚C	<8h	22
Paper	SARS-CoV	Room Temperature	4-5day	21
Silicon rubber	HCoV	21˚C	5day	23
PVC	HCoV	21˚C	5day	23
Teflon	HCoV	21˚C	5day	23
Ceramic	HCoV	20˚C	5day	23

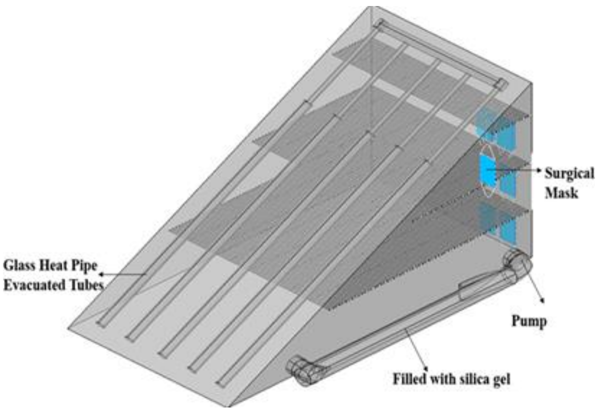

Figure 2. An overview of a solar dryer.

sensors, the temperature changes in each part were measured during the day. Figure 2 shows a schematic picture of a solar dryer for disinfection.

3. Results and Discussion

Many organizations and hospitals are looking for a way to disinfect disposable masks for reuse [24]. Medical masks according to European Standard EN 14683:2019+AC:2019 and ASTM F2100- 11 standards established, also comply in Directive 93/42 CE or Regulations UE/2017/745. Medical masks should be discarded after use according to technical standards [25], because they are not designed for sterilization. However, due to over-consumption, reusing has been considered as one of the issues proposed by the communities. It should be noted that any method used to disinfect the mask must ensure its effectiveness against COVID-19 [6]. Facial masks can be reused for 30 minutes after settling at 65-70˚C [6]. This method treats the least damage to the mechanism and keeps the filtering effect above 95% [26, 27]. As shown in Table 2, all of the proposed methods lead to changes and reductions in the quality of the mask. According to previous studies, the use of high temperature and hydrogen peroxide has the best effect on disinfecting the mask. But using solar radiation without direct contact gives better results in mask disinfection.

3.1. Heat transfer process

It should be considered in the selection of equipment for high heat transfer in the system. In the designed system, there is less heat loss. After exposure to the sun, each element inside and outside the system is considered as a source of heat and is effective to increase the temperature of the system, also facilitate the disinfection of the masks. This study was conducted in April month. The highest temperature increase was seen between 11:00 a.m. and 14:00 p.m.

In addition to increase the air temperature, during these hours the paraffin temperature rise above 200˚C, which leads to the transfer of heat from the copper pipes to the air inside the system through the convection process. The most important reason for temperature increasing and heat transfer is solar radiation, which reaches to 1128 W/m^2.

Also, the internal cumulative solar radiation reaching the system was 3036 Wh/m^2. The air temperature of the system has reached a maximum of 54˚C at noon, which is also possible in hot seasons above 70˚C. This means that the keeping time of the mask varies according to the internal temperature of the system. In Figure 3 is shown

Table 2. Changes in the mask during various disinfection processes [28]

Process	Face mask deformation (yes/no)	Fit test outcome +/-
Control	N/A	. +(162)
1. 60˚Celsius cleaning without detergent and disinfectants	No	. -(60)
2. 90˚Celsius cleaning without detergent	Yes	N/A*
3. 90˚Celsius cleaning with detergent	Yes	N/A*
4. Hydrogen peroxide sterilization 1x	No	. +(151)
Hydrogen peroxide sterilization 2x	No	. +(103)
Hydrogen peroxide sterilization 3x	No	. -(28)
Hydrogen peroxide sterilization 4x	Yes	N/A*
5. Steam sterilization 134˚C	Yes	N/A*

Table 3. Thermal conductivity of system equipment

Thermal Conductivity (W/mK)		Reference
Air	0.02	28
Paraffine	0.21	28
Polycarbonate	0.19	28
Earth	1.5	28
System aluminium box	235	29
Glass heat pipes evacuated tubes	1.13	28
Copper pipes	401	31
Polyurethane İnsulation	0.03	28

the important factors for increase the internal temperature of drying system.

The heat transfer process can be clearly seen by the difference between the internal and external temperatures of the system. The highest thermal conductivity in this system relates to aluminum and copper pipes.

Thermal conductivity is the heat transfer from one part of the system to another part and is defined as the ability of equipment to transfer heat. Ambient temperature is the important factor that affect the material thermal conductivity. The process of heat transfer from the higher

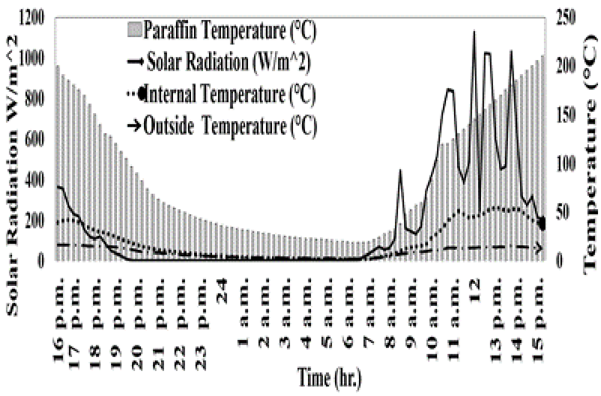

Figure 3. Factors affecting the internal temperature of the system

temperature region to the lower temperature is to achieve thermal equilibrium. During a molecular phenomenon, the conduction process occurs as a chain. The highest effective convection heat transfer is due to the movement of air near copper pipes. The thermal conductivity of all materials was used in drying system are shown in Table 3.

The rate of heat flow from the front of system through the polycarbonate in a period of a 24 hours in Equation (1) was 106.5 MJ. The average temperature difference between inside and outside of the system was 30˚C.

Rate of heat flow (W)

$$\frac{Q}{t} = \frac{KA\Delta T}{d} \quad (1)$$

K=Coefficient of thermal conductivity (Wm-1K-1)

A=area of object m^2

ΔT= Temperature difference (K or˚C)

d = Thickness of material (m)

In this system, according to previous studies, the amount of internal cumulative solar radiation reaching the system for 24 hours per season has been calculated.

The most important determinant variable in this project is solar radiation, which increases the internal temperature of the system and decreases the retention time of the mask in the system.

The amount of internal cumulative solar radiation that reaches the system in spring, summer, autumn, and winter, respectively, include (3036, 3234, 2280, 1989 Wh/m^2).

According to previous researches, the relationship between time factor and cumulative solar radiation of different products will increase 1/3 of the time factor if the cumulative solar radiation triple.

3.2 Data analyzing by MATLAB program

In this research, by MATLAB version R2018b software, a relationship between solar radiation and internal temperature and moisture was indicated by using the polynomial model in Table 4. The X value represents internal temperature (℃), the Y value represents the internal moisture (RH %), and the f (x, y) represents the internal solar radiation (W/m^2). This regression was defined the values of the selectivity coefficients.

According to the p00, p10, and p01 range values, 95% confidence was determined. 'SSE' specified the sum of squares due to error and by closing to zero the random error decreases and the probability of proper prediction increases. Adjusted R-square defines the residual degrees of freedom. RMSE (Root Mean Square Error) means is fit standard error and standard deviation of the random element also low RMSE values shows the data are fitted. The R-square values was higher than 0.9. The curve fitting of this model because of high correlation coefficient is well. This model was investigated by using two R2 and RMSE parameters.

Conclusion

In special conditions caused by pandemics, appropriate solutions should be considered for the problem of lack of masks. The reuse of the facial mask seems a good solution. Studies have shown that the most important factors for disinfection are high temperature, duration and intensity of sunlight. In this study, a suitable model for evaluating the efficiency of solar dryers for disinfection process is presented. In a solar dryer, the choice of parts and components used in the construction of the system is important in terms of heat transfer capability. The selected parts should have the highest thermal conductivity and high power in receiving sunlight during sunny hours. In this research, in addition to the importance of copper pipes used in glass tubes, paraffin-wax (phase change material) for heat storage is also important. In this solar dryer, the maximum internal temperature reaches to 54 ° C, and the disinfection process is performed within 24 hours by receiving a maximum of 1128w / m^2 of solar radiation. In general, 3036 Wh/m^2 internal cumulative solar radiation is enough to disinfect masks. In warmer seasons, the duration of disinfection can be reduced. This system is designed for drying on a small scale for approximately 500 facial masks. It is also possible to use this technology in different industries for more specialized purposes. The R-square values above 0.9 and low RMSE values prove that the data is fit. This system can be upgraded for different purposes and industries.

Simultaneously with the decrease of solar radiation, the duration of disinfection and exposure of the mask to the sun increases.

Depending on the type of system efficiency and the seasons, more solar radiation can be absorbed by increasing the number of glass tubes and installing reflectors. In addition, by placing more silica gel in the system, more moisture is discharged from the system. Also, by replacing different phase change materials than paraffin, more heat can be stored. This system has low risk and high security for workers. Also, the high cost of providing a new mask or throwing away used masks can suggest a reuse process.

Table 4. Relation between internal temperature° C and solar radiation(W/m^2)

Linear model Poly1	f(x,y) = p00 + p10*x + p01*y
Coefficients	95%
p00	-641.1 (-759.8, -522.5)
p10	17.56 (15.49, 19.62)
p01	7.317 (5.91, 8.723)
SSE	1.945e+05
R-square	0.9723
Adjusted (R- square)	0.9717
RMSE	46.49

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